Extreme ultraviolet interferometry: at-wavelength alignment of diffraction-limited, prototype lithographic optics

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INTRODUCTION

The quest to develop extreme ultraviolet (EUV) optics for use in next-generation projection lithography systems providing sub-100-nm resolution has led to various innovations in EUV wavefront metrology,[1,2] including the EUV phase-shifting point diffraction interferometer (PS/PDI),[3-5] developed by researchers from LBNL's Center for X-Ray Optics. The PS/PDI, and the EUV lithography program it supports, is described in detail elsewhere in this compendium.[6]

The PS/PDI is a diffraction-class interferometer,[7-9] in which the illumination and reference waves are created by pinhole diffraction. Furthermore, a diffraction grating is used as the beam-splitting and phase-shifting element. This diffraction configuration allows the PS/PDI to attain high reference-wavefront accuracy, recently measured to be better than $\lambda_{EUV}/330$ (0.4 Å) within a numerical aperture (NA) of 0.082.[10]

ALIGNING OPTICS USING THE 10×-SCHWARZSCHILD PS/PDI

The PS/PDI currently installed at ALS beamline 12.0.1.2 was designed and implemented to characterize and align 10×-reduction Schwarzschild objectives used as prototype lithographic small-field stepper optics. These optics are used as the imaging system in two EUV micro-steppers developed at Sandia National Laboratories, and have played a key role in the recent rise of EUV lithography as one of the favored *next-generation-lithography* options.

The PS/PDI has been in continuous use and under ongoing development since 1996. Recent improvements include greatly extended dynamic range and measurement bandwidth. The interferometer has been successfully used to characterize a multitude of 10×-reduction EUV lithography optics. During the past year the PS/PDI was utilized to align two new state-of-the-art 10×-reduction Schwarzschild objectives. These optics were fabricated to the same optical tolerances as those used in the commercial-class large-field 4-mirror optical system concurrently being developed by the EUV lithography program.[6] The optics have been designed to provide better than $\lambda/20$ rms wavefront quality with an image-side NA of 0.088, providing diffraction-limited resolution below 100 nm. They utilize molybdenum/silicon multilayer coatings designed for peak reflectivity at 13.4-nm wavelength.

The system wavefronts of two newly fabricated optics, aligned with EUV interferometry are summarized in Fig. 1. Based on fitting to the first-37 Zernike polynomial terms,[11] the rms wavefront error magnitudes (σ) for optics labeled B1, B2 are 0.60 nm (0.045 waves), 0.63 nm (0.047 waves), respectively, within 0.088 NA. In both cases the wavefront quality goal has been surpassed.

Although two-pinhole null tests have been used to measure the accuracy of the PS/PDI to be better than $\lambda_{EUV}/330$ (0.4 Å),[10] the ultimate test of accuracy for a system designed to align lithographic optics are printing results. Figure 2 shows images taken both before and after EUV

alignment of the B2 optic described above. The images demonstrate the performance of the optic with both isolated and dense 100-nm features in two directions, in and out of the optimal focal plane. The images were recorded using the EUV Microstepper at Sandia National Laboratories, and demonstrate that the PS/PDI has successfully achieved diffraction-limited alignment.

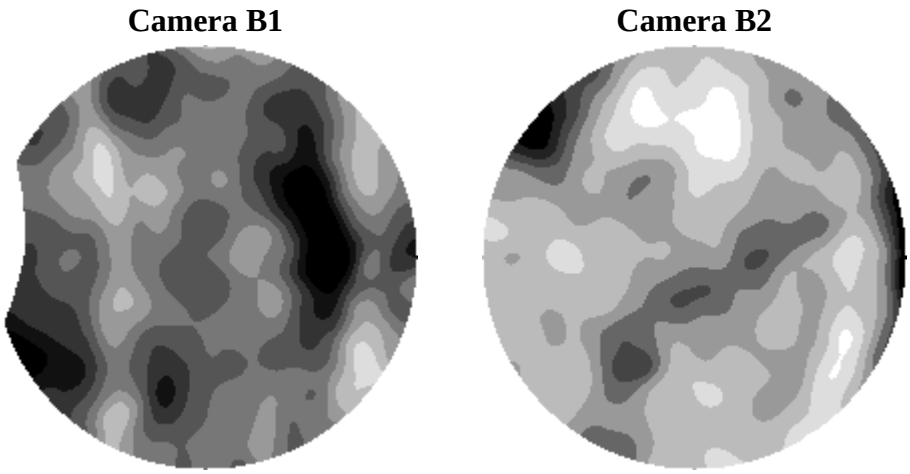

Fig. 1. PS/PDI-measured wavefronts of two recently fabricated 10×-reduction EUV Schwarzschild cameras. The wavefront statistics are quoted over an off-axis NA of 0.088, and are based on 37-term Zernike fitting. The displayed wavefronts, however, include higher spatial frequency features, and are individually scaled. The measurement wavelength was 13.4 nm.

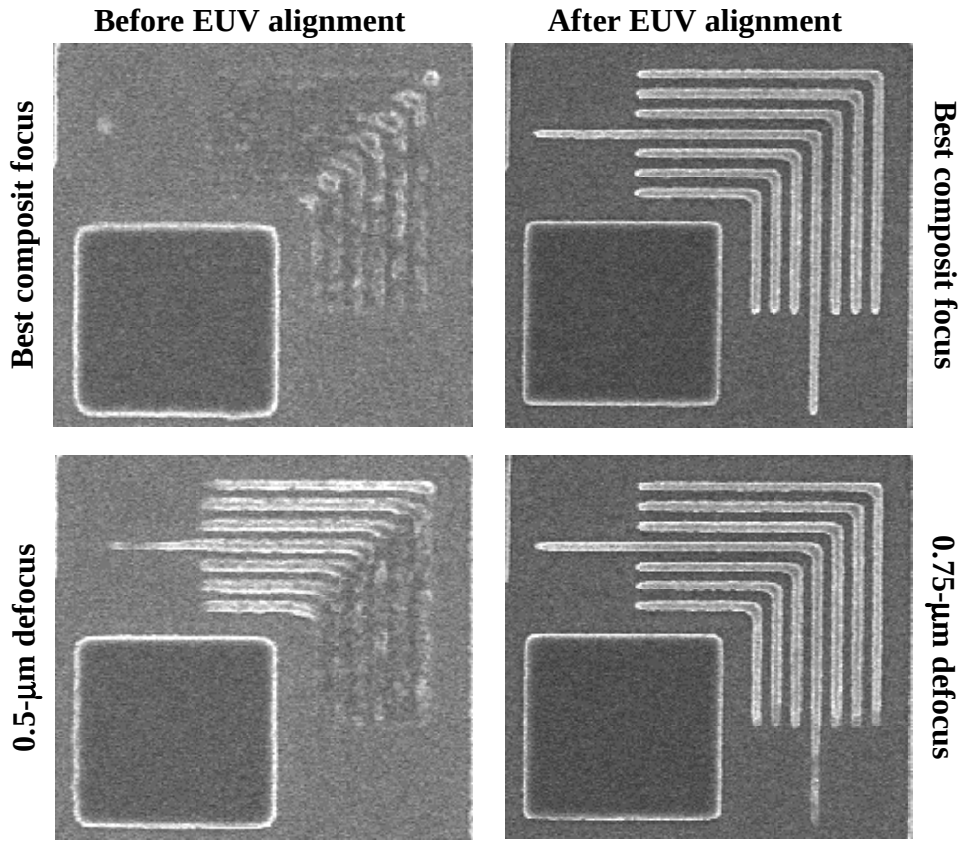

Fig.2. Images taken both before and after EUV alignment of the B2 optic. The images demonstrate the performance of the optic with both isolated and dense 100-nm features in two directions, in and out of the optimal focal plane. The images were recorded using the EUV Microstepper at Sandia National Laboratories.

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